# Optimal Placement of Renewable Distributed Generation in Radial Distribution Network: A Review

Lucius C. Mawanga, Peter K. Kihato and Michael J. Saulo

***Abstract*—**Optimal placement and sizing of distributed generation is one of the most studied areas in the current distribution network planning and operation. It is well known that the power network has always had a passive distribution network and introduction of distributed generation into the network introduces various challenges including voltage instability, equipment overloads, losses, and harmonics among several others. In order to avoid such technical challenges and also gain the best out of the integration of distributed generation, optimization studies are performed to select the best location and size. There are various studies that have been done in placement and sizing of distributed generation including use of analytical approaches, mixed integer linear and non-linear programming techniques, heuristic algorithms, fuzzy theorem and the list is not exhaustive. Of late, renewable energy distributed generation is being considered since it is a free resource and environmentally friendly. However, these bring further challenges in consideration of the variations in generation versus the objective to meet the load demand. This paper therefore aims to review the efforts that are being done to do an optimal placement that considers variable renewable energy resources as used in radial distribution network (RDN).

***Keywords*—**Distributed Generation, Optimal Location and Sizing, Radial Distribution Network, Renewable Energy Resources.

## I. INTRODUCTION

THERE is a growing interest in the usage of grid connected renewable distributed generation to support the power system. Various reasons for the consideration of such technologies include their nature being environmentally friendly, non-depletable resources, and their investment costs keep getting cheaper by and by[1]. Just like any other distributed generation, the renewable distributed generation (RDG) help also in loss reduction, voltage profile enhancement, reliability improvement and also deferral of network upgrades[2], [3][4].

Various techniques of sizing and siting are being considered including analytical, heuristic and meta-heuristics. However, in addition to the problems that may be introduced by DGs to the distribution network if not planned carefully like reverse power flows, feeder and transformer overloads, over-voltages, and harmonics, some of the RDGs have a variable generation pattern that may interfere with the operation of the network in terms of generation-load balancing. Therefore, studies are being and have been done to size the technologies for RDN considering the uncertainties of generation and load.

Many studies just like in [5], [6] utilize renewable energy sources in the optimal placement and sizing problem but either do not consider the stochastic nature, or cushion it by usage of biomass or other form of dispatchable DG. For the studies that have considered uncertainties either possibilistic means or probabilistic means have been used to model the generation and sometimes even the load. For example, the Fuzzy Mathematical Models are considered possibilistic since predictions can be modelled efficiently without any problem-specific knowledge. On the other hand, the probabilistic models are dependent on measured data and their success depends on such data samples and knowledge of the distribution of errors[7]. The use of probability distribution functions (PDFs) developed from data is an example of probabilistic models.

The problems are formulated considering either single objectives or multiple objectives looking at parameters like minimisation of real and reactive power losses, node voltage deviation, line loading, short circuit capacity, reduction of carbon emission, reliability of the network and even installation and operation costs. Constraints may include thermal limit of network branches, limits of node voltages, DG sizes among many others[8]. Most of the heuristic studies were mainly looking at multi-objective optimization and also looked much more into the cost factor in distribution planning whilst the analytical techniques mostly considered only voltage improvement and power loss minimisation.

Rest of the paper is organized as follows: Section II presents types of distributed generation as generally classified by experts. Section III is dedicated to the modelling of RDG. Section IV looks at the efforts that have been made in optimal placement of RDG and Section V is a tabular summary. Finally, the major contributions, challenges and conclusions are summarized in Section VI.

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## II. TYPES OF DISTRIBUTED GENERATION

According to [6][9][10][11][12] distributed generation can be categorized into classes according to the power output characteristics. Though there doesn't seem to be a uniform classification by the authors on which specific class has such and such power characteristics, there is an agreement to the following categories. Thus, it can be established that there are four types;

1. DG only injecting active power, P: These comprise Photovoltaic, micro turbines, fuel cells, which are integrated to the main grid with the help of converters/inverters
2. DG only injecting/absorbing reactive power: Could be synchronous compensators such as gas turbines.
3. DG injecting both active reactive power, P and Q: DG units that are based on synchronous machine (cogeneration, gas turbine, etc.)
4. DG injecting active power P, but absorbing reactive power Q: Mainly induction generators that are used in wind farms

It must be noted that the resources being reviewed in this article, Solar and Wind, belong to Types 1 and 4 respectively.

## III. MODELLING OF RDG UNCERTAINTIES

A proper model of the distributed generation is very important for conducting load flow studies in order to assess impacts on the network [9]. The DG's can either be modelled as PQ (if small) or PV (if big) depending on size of their output power or their control techniques for those connected through inverter/converter.

The energy sources of DGs can be categorised into stable energy sources, such as fuel cell and micro-gas turbine, and unstable energy sources, such as wind and solar[13]. The unstable sources are also referred to as non-dispatchable since they cannot generate as per the exact load profile as they are dependent on real-time variable provision of nature. This is the reason why their modelling assists in selecting the best-case scenario as established from past data in meeting the load demands.

Literature [14]–[17]has shown that solar, and wind profiles can be represented by using known distribution functions as stated below.

Solar irradiance follows a Beta probability density function (PDF) given by the following equation;

$$f_b(s) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} * s^{\alpha-1} * (1-s)^{(\beta-1)} & for\ 0 \le s \le 1, \alpha \ge 0, \\ & \beta \ge 0 \\ 0 & otherwise \end{cases} \tag{1}$$

Where,

$f_b(s)$ – is the Beta distribution function of $s$

$s$ -is the solar irradiance

$\alpha, \beta$–are the parameters of the Beta distribution function

Similarly, wind profile can be estimated using the Weibull probability density function as follows;

$$f_w(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] (2)$$

Where,

$f_w(v)$ – is the Weibull distribution function of$v$

$v$ -is the wind speed

$k$ –is the shape parameter

$c$– is the scale parameter

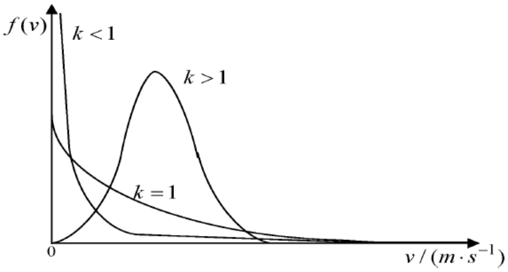

*Figure 1: Weibull distribution of the wind speed*[18]

From measured data, the solar and wind PDFs can be estimated and a Monte Carlo Simulation is then implemented using the to select operating states of the RDG for carrying out load flow. Stochastic load flows are then run per selected generation state and eventually results obtained of optimal locations and size in the RDN.

## IV. OPTIMISATION OF RDG

### A. Analytical Techniques

Various analytical approaches are utilized dependent on some engineering concepts for placement and sizing of distributed generation. For example, some rules of thumb like the "2/3 rule" which is used in capacitor placement installs 2/3 capacity of a uniformly distributed Var load downstream of a substation by placing it at 2/3 distance along the feeder and may also be used in placement of DG. However, such rules can occasionally be in error as they are approximate methods. More analytical approaches keep being developed considering that they remain precise and effective though they may require exhaustive manipulations to achieve resultsas opposed to AI. It is also stated in [1] that despite being accurate they are best suited to small and simplistic systems but perform unfavorably for large and complex systems. Below are several analytical techniques that have been used in optimal placement of renewable energy sources in a distribution system.

In [19] analytical expressions were developed by considering reduction of feeder current along a feeder of length $l$through installation of a DG with unity power factor at a location $x$ such that losses are reduced to zero (Fig. 1). If the position violates voltage constraints then a position close to $x$

is selected to correct the situation. Formulas used were derived starting from the feeder current daily average curves at a time $T_i$ and $T_{i+1}$then relationships were established with terminal voltage, the drop along the feeder, DG current, and power loss.

$$P_{loss}(x_o,T_i) = \int_0^{x_0}\left(\left|\int_0^{x} I_d(x,T_i)\right|\right)^2 .Rdx + \int_{x_o}^{l}\left(\left|\int_0^{x} I_d(x,T_i)dx - I_{DG}(T_i)\right|\right)^2 .Rdx \tag{4}$$

Where,
$I_d(x,T_i)$– is the demand current measured at any point *x* along the feeder at a time $T_i$
$I_{DG}(T_i)$ - is the current injected at node *i* by a distributed Generator at a time $T_i$
$R$ – is the resistance of the feeder
$x$, $x_o$ - represent positions long the feeder of length *l*

Theoretical and after-simulation locations of the DG were established from the derived formulas being the integral of the area under the curve and they were found to be in agreement. The study was performed for uniform, central and increasing distributed loads on a radial feeder with time invariant loads. Then using time variant load and wind generation from a typical household in Northwestern USA and rural area in South Central Montana respectively, the study was performed for uniformly 0distributed loads and locations for DG placement located using the analytical formulas. Results of simulations did show that the approach was effective. The author acknowledged that the study doesn't involve iterative approach and has no convergence problem however in practice there might be constraints which may affect the DG placement. In this study optimal size, economic and geographical locations were not considered for optimization.

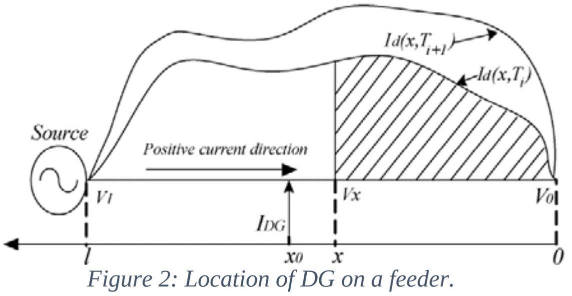

*Figure 2: Location of DG on a feeder.*

Furthering work of its reference [6], Hung, et al in [20], developed analytical expressions from the exact loss formula (5) which is a function of active and reactive power injections at all buses for calculating size and optimal power factor of DG simultaneously. Biomass and wind generators were used for the study in performing optimal placement and sizing firstly for each technology separately and then together as a hybrid. All generators are assumed that they can be installed at any bus. The load and wind generation profiles of a representative day for each of the four seasons were utilized. The biomass generation profile follows the load pattern while that of wind as per its profile. Thus 4 days (96 hours) are taken to represent a full year. To achieve the total annual energy loss, the loss calculated for the representative days are multiplied by a factor. The study was performed on an IEEE 69-bus.

$$P_{loss} = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j + P_iQ_j\right)\right] \tag{5}$$

Where,
$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_i);\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_i)$
$V_i, V_j$ are complex voltages at respective buses *i* and *j*
$r_{ij}$ is the resistive part from bus impedance matrix
$P_i, P_j$ are active power injections at respective buses *i* and *j*
$Q_i, Q_j$ are reactive power injections at buses *i*and *j*

According to [21], a study was performed in distribution planning with incorporation of distributed renewable energy resources. The study conducted separate investigations on renewable DG for voltage support and RDG for energy loss reduction in the system. First the uncertainty of generation and load were modelled using the Gauss, Beta and Weibull distribution functions respectively. Then optimal placement was done using analytical formulas derived based on Newton Raphson and then Backward/Forward Load flow methods. The methods calculated the most efficient power factor of RDG then step by step increase the DG for the most optimal size for voltage improvement on all other buses. The least RDG of all the buses with the most voltage improvement is then selected as the most optimal. The method was compared to exhaustive search methods and results proved to be efficient. The results also found that DG's improving both active and reactive power are more effective in voltage improvement than those just delivering active power. It also found out that DG has to be operated at its best power factor for active power and reactive power injection for maximum voltage support.

Atwa, et al[22] performed a study based on probabilistic generation-load model combining all possible operating conditions of generation for the renewable energy units for energy loss minimization. The constraints considered included feeder capacity, penetration level and discrete sizes of the units in the minimisation of energy losses. Several scenarios as described below were ran;

*Scenario #1*: the reference scenario, in which no DG units are connected to the system (base case);
*Scenario #2*: only wind-based DG;

*Scenario #3*: only biomass DG units;
*Scenario #4*: only solar DG units;
*Scenario #5*: wind-based DG with solar DG;
*Scenario #6*: wind-based DG with biomass DG;
*Scenario #7*: solar DG with biomass DG.
*Scenario#8*: a mix of wind-based, solar and biomass DG.

The study utilized specific three-year data from Waterloo University for an Ontario 41-bus system case study that had predetermined buses for placement of wind and solar that were modelled using Weibull and Beta probability density functions respectively. Four representative days each for the four seasons were used having 96-time segments for development of the PDFs. The load profile was considered to be a percentage of the peak load as per IEEE-RTS system.

Based on the previous work in , Bahreyni et al in[23]also discussed the determinative role in future of wind and solar power generation and therefore recognized the need for precise modelling of their output power for use in the power distribution networks. A novel single line power flow model based on the network elements termed ABCD parameters corresponding to the sending and receiving ends was developed and used. A probabilistic combination of generation-load states was used in the load flow and solved by The *General Algebraic Modeling System* (*GAMS*) using a nonlinear modeling system for loss minimization. Power balancing equation, voltage limits and penetration level of DG were considered to be the constraints.The difference in the studies by Atwa and Bahreyniare that the former utilized biomass as well as used the static load flow equations(SLFE) as opposed to the ABCD parameter based load flow by the latter.[24]

[25] compared the loss reduction from installing a solar PV DG against those from a firm power generation DG on an actual 22kV Distribution System in Thailand. Loss sensitivity factor was used for selection of the bus for placement of the firm DG and then losses were determined. Then solar PV-DG that operates at unity power factor and without battery was placed on the same location with consideration of the uncertainties in radiation, ambience, and load as modelled by Monte Carlo Simulation. Results showed that PV-DG size was supposed to be bigger at 1.8MWp compared to the DG case of 1.14MW to achieve losses of 24.52kW and 19.44kW respectively. However, the average output of solar considering uncertainties was 0.76MW due to variation of solar irradiance and ambient temperature. Constraints were strictly considered to be the voltage limits and total harmonic distortions only.

[26] used three scenarios for calculating the effect of wind-based DG seasonality and uncertainty on distribution system losses. The scenarios utilized peak load and constant power output of wind (OPF formulated as Non-Linear Programming Method), average load and a probabilistic Weibull pdf wind generation (normal power flow), and finally measured load and measured wind data carried out hour per hour (load flow) respectively to observe the effects on annual energy losses.

The above studies have shown that analytical techniques can be used in siting and sizing of RDGs. They are precise and achieve expected results by utilization of basic mathematical manipulations and assumptions. However, it can be hectic for complex system considering the numerous number of buses and the complex nature of the decision variables to be considered. This is the reason why heuristic techniques are considered as they can manipulate complex combinatorial problems like the problem of different states of RDG in a considerable amount of time.

### *B. Heuristic Methods*

Owing to the challenges faced by analytical techniques, heuristic and meta-heuristic techniques have also been used under various studies in the placement of variable RDG as explained below.

In [27]a multi-objective model that includes installation and operation costs of DG, cost of power losses and cost of unsupplied load is proposed. The load, generation and electricity market price uncertainties are modeled by a piecewise load duration curve, wind PDF and fuzzy theorem respectively. A Monte Carlo based approach is proposed for the evaluation of power losses and load not supplied with GA procedure as a solution algorithm.

In [28] a study was done on placement of DG considering uncertainties of generation, load, equipment reliability indices (failure rate, repair time) and electricity market price. The generation and load were modelled with probability density functions through use of Monte Carlo Simulation whilst the reliability indices and tariff were selected by Fuzzy Set Theory. The objective functions considered include system reliability, power losses and investment cost for DG installation and operation. The paper considered the use of wind-based DG but stated that a similar approach can be used for another renewable based DG. Several years data in wind installation location was gathered and used for predicting a precise model for wind speed variation. The study considered a correlation between wind and load by assuming wind to be the independent variable whilst load dependent. Thus, occurrence probability of each load level is calculated if specified wind speed occurred and voltage and loading constraints were not considered. A levelized time varying load curve was used. Power losses and reliability index for any instant were calculated upon Monte Carlo random sampling of wind speed then a final objective function calculated through GA to find the most optimal solution.

In [29] a multi-objective siting and sizing of wind power generation is carried out by using the ε-constrained technique where cost of energy not served, voltage profile and power quality due to harmonic distortions of the network are the combined objective function. Three sub-areas of a distribution network have different wind profiles whose PDFs have been sampled using Monte Carlo Simulation and load flow using PLF is performed. A double trade-off procedure is applied where pareto-optimal solutions are obtained by the ε-constrained technique and the most feasible solution achieved by evaluating them by using GA.

The authors in [17] presented an approach to a coordinated planning of distribution network and distributed generation considering uncertainties of output of DG and load. This utilized types of DG, location, capacity and lines in need of upgrade as variables and considered investment, power purchasing, network loss and power failure as objectives. In face of uncertainties of load and generation, first the corresponding probability models are established, then the Latin Hypercube Sampling (LHS) technique is adopted to get samples and research scenarios are obtained after sample reduction. A multi-objective chaos improved PSO based on theory of pareto-optimal solution set is proposed to solve the model and an IEEE 33 bus system was used to test the effectiveness and feasibility of the model and algorithm.

Under the chance constrained programming framework(CCP), the authors in [18] did an optimal siting and sizing of DG considering the minimization of investment, operating, maintenance, network loss and capacity adequacy costs. Genetic Algorithm with a Monte Carlo embedded function was used in the simulations. Interesting factors in the study included the maintenance cost of RDG as zero, a decision variable of whether installation at a node will be allowed or not, number of operations per year of a DG, probability of tariff change, and the study considers multi-objective placement using AHP algorithm that assists in determining the weighing coefficient for each objective. The chance constraint of current, the equality constraints of load flow equations, inequality constraints being active and reactive power outputs of DG, penetration capacities of DG, and voltage limits. A factor of load growth was also considered in the simulations for a period of three years. In this study, the feasibility of population of samples generated by GA is checked with Monte Carlo simulation and the roulette wheel used in the selection. A proper set of initial solutions determined by the Monte Carlo simulation where a confidence level is used to evaluate survival. The study found out that the growth in renewable DG and PEV's increased and the fueled DG decreased indicating the viability of using RDG in the distribution network. Also, there was an improvement in voltage at nodes and reduced losses as well as enhanced power supply reliability.

[30] did an optimal placement of renewable energy generation considering uncertainties using Intelligent Water Drops Algorithm. The selection of the location for placing a DG was done by using a Voltage Controllability Index (VCI) which foretells the controllability of the buses in the system. The sizing was done with the help of the IWD algorithm. The generation of wind and solar was indicated by different states categorized hourly according to their variability using probability density functions whilst the probability of load was considered to be one. A representative day is taken in a year and considered to be the state of generation for all days of the year. Three states for solar and three states for wind are assumed for the study and a total of 108 load-generation states are obtained for the year. It must be noted that the study utilized the generations states from (reference).

[31] recognized that most studies neglected the stochastic nature and intermittency of solar in their studies. As such the author developed a technique for optimal placement of solar power on a 37-bus system using Genetic Algorithm and stochastic load flow. In the simulations, the solar generation was performed considered to be in three models namely unity power factor (model 1), constant lagging power factor (model 2) and varying lagging power factor (model 3). Results indicated that model 3 had the highest reduction in active power loss and model 2 highest reduction in reactive power loss. And overall comparison did show that model 2 improved better on both reduction of active power loss and voltage profile than the base case.

In [8] a fuzzy approach that used the triangular functions was considered for modelling uncertainties of generation and load.The objective functions being minimizations of network power loss and node voltage deviation. A single objective function with weights was then formulated after de-fuzzifying the separate objective functions in order to find the best set of pareto-optimal solution through the use of Genetic Algorithm.

Using three different wind profiles, [32] performed an optimal placement and sizing of distributed generation based on Genetic Algorithm and Decision Theory.

Ochoa et al [33] looked at a time-series steady-state analysis of technical issues namely, energy export, losses and short-circuit levels upon placement of distributed wind power generation (DWPG). The multi-objective programming approach evaluated the stated parameters using the nondominated sorting genetic algorithm (NSGA) to find configurations that maximise integration of DWPG while satisfying thermal and voltage constraints considering hourly load demand and wind profiles for a 34-bus network in the UK.

An Evolutionary Programming based optimal placement of Solar PV and Wind generation on a 69-bus distribution test system of Gujarat, India was carried out in [34]. The discrete probabilistic generation and load states are obtained from their pdfs and measured values respectively. These discrete time segments are used for carrying out load flow with a combination or single technology in achieving active energy loss reduction. A sensitivity index is used to reduce the search space and thus the computation time. Results are compared by also simulating using Exhaustive Search methods and GA.

[35] optimized the placement of wind, solar and biomass considering their reactive power capabilities and modeled the uncertainties of the RDG and load using Weibull, Beta and Gaussian distribution functions respectively. The objective is to minimize the total cost incurred by a utility over a planning period. The historical data used is divided into different segments from which hourly states of load and generation are obtained as shown in Fig. 3. The search space (segments) is reduced by selecting representative states which are then used for load flow. TRIBE PSO is then used to explore feasible candidate solutions through approximate evaluation to form a representative set for Ordinal Optimisation which does intensive assessment for candidate solutions so as to find the

optimal and near-optimal solutions.

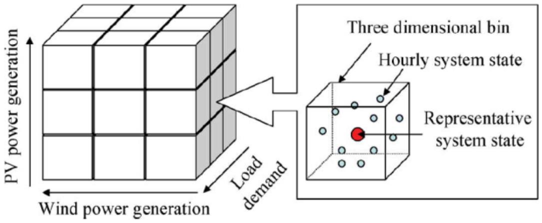

*Figure 3: Generation of Representative System States*

## V. APPENDIX

*Table: Existing Placement Studies on RDG*

| Reference | Objective | Constraints | Power Factor | Load | Technique |
|---|---|---|---|---|---|
| Wang, et al | Minimise power loss | Voltage limits | unity power factor | Varied | Analytical |
| Hung, et al | Minimise power loss | Branch current, Bus Voltage, DG Size | non-unity power factor | Varied | Analytical |
| Zou | Minimise Power Loss | Branch Current, Nodal Voltages | non-unity power factor | Varied | Analytical |
| Atwa, et al | Minimise Energy loss | Feeder Capacity, Discrete DG Size, Penetration Level, Voltage limits | unity power factor | Varied | Analytical |
| Bahreyni, et al | Minimise Annual Energy loss | Power balancing, Voltage limits, penetration level | Unity power factor | Varied | Analytical |
| Tayjasanant, et al | Minimise Power Losses | Voltage Limits, Harmonics | Unity power factor | Varied | Analytical |
| Atwa, et al | Minimise Annual Energy loss | Penetration, Voltage, Feeder Capacity, Power balancing | unspecified | Varied | Analytical |
| Hadian, et al | Minimise costs of power losses, unsupplied load, installation and operation | Unspecified | Non-unity power factor | Varied | GA, Monte Carlo |
| Haidian, et al | Minimise costs of power losses, unsupplied load, installation and operation, | DG Capacity at node | Non-unity | Varied | Fuzzy, Monte Carlo, GA |
| Carpinelli, et al | Minimise cost of energy losses, voltage deviations, harmonic distortions (HD) | Feeder Capacity, Voltage limits, Short Circuit Level, Voltage Harmonics, Total HD | Unspecified | Varied | Monte Carlo, GA |
| Hu, et al | Minimise costs of investment, operation and maintenance, active power loss, power failure | Power Balancing, Voltage Limits, Branch Current, DG Size, Connectivity | Unspecified | Varied | Latin Hypercube, PSO |
| Liu, et al | Minimise costs of investment, operating, maintenance, network loss and capacity adequacy | Feeder current, Power Balancing, DG Power Limits, DG penetration, voltage limits | Unspecified | Varied | Monte Carlo, GA |
| Sowmya, et al | Minimise Power Loss | Voltage Limits | Unspecified | Constant | IWD |
| Caasi, et al | Minimise Power Loss | Voltage Limits | Unity, Non-Unity | Constant | GA |
| Ganguly, et al | Minimise Power Loss and Voltage Deviation | Voltage Limits, Branch Thermal Limit, DG Power Limits | Unspecified | Varied | Fuzzy, GA |
| Ochoa, et al | Maximise Energy Export, Minimise Power Losses and Short Circuit Levels | Voltage Limits, Branch Thermal Limit | Unity | Varied | NSGA |
| Khatod, et al | Minimise Energy Loss | Number of DGs, | Unity, Non- | Varied | EP |

| | | | | | |
|---|---|---|---|---|---|
| | | Power Balancing, Voltage Limits, Line Loading | Unity | | |
| Zou, et al | Minimise costs of Unsupplied Energy, Operation and maintenance, fuel cost, purchased energy, | Penetration of DG, DG Size, | Unity, Non-Unity | Varied | TRIBE-PSO |

## VI. CONCLUSION AND FUTURE CONSIDERATIONS

The random placement of renewable distributed generation can have undesirable effects in the voltage profile, loss and reliability of distribution networks. The major challenges in placement of RDG include the intermittent nature in consideration of meeting the load demand, coming up with the right mathematical models, and selection of a convenient tool for handling the complex combinatorial task. This paper has looked at efforts that have currently been used for optimal placement of RDG. It has been noted that new analytical approaches keep being developed for optimal placement of RDG considering their more direct approach. However, they are limited to simple systems. Heuristics approaches on the other hand can be used for complex systems and have also been employed with different mathematical models and the use of Monte Carlo and Latin Hyper Cube as well as other statistical means for incorporating the uncertainty of RDG and load. In the cases where PDFs are being used, raw data is utilized to come up with the means and standard deviation for estimating the PDFs.

However, much work has been considered in the multi-objective placement which usually obtains pareto-optimal solutions which are in short compromised solution in the sense that they do not explore improvement of one parameter to the maximum but trade-off to improve several others at the same time. It can also be seen from literature that there are less studies utilising heuristic approaches and mainly GA is the most used. The use of sensitivity indices in aiding selection of locations for placement of RDG has also not been fully utilised in these studies. It is the view of this paper that such approaches must be considered in future studies to ensure optimal tools are discovered in dealing with usage of RDG in Radial Distribution Networks.

## REFERENCES

[1] P. Prakash and D. K. Khatod, “Optimal sizing and siting techniques for distributed generation in distribution systems : A review,” *Renew. Sustain. Energy Rev.*, vol. 57, pp. 111–130, 2016.

[2] D. Q. Hung, N. Mithulananthan, and R. C. Bansal, “Analytical strategies for renewable distributed generation integration considering energy loss minimization,” *Appl. Energy*, vol. 105, pp. 75–85, 2013.

[3] C. Wang and M. H. Nehrir, “Analytical Approaches for Optimal Placement of Distributed Generation Sources in Power Systems,” p. 1.

[4] K. Zou *et al.*, “An Analytical Approach for Reliability Evaluation of Distribution Systems Containing Dispatchable and Nondispatchable Renewable DG Units,” vol. 5, no. 6, pp. 2657–2665, 2014.

[5] D. K. Tanwar, Surender Singh; Khatod, “Optimal Placement of Renewable DGs in Balanced Radial Distribution SYstem,” *IEEE Trans. Power Deliv.*, pp. 1–6, 2016.

[6] D. Q. Hung, N. Mithulananthan, and R. C. Bansal, “Analytical Expressions for DG Allocation in Primary Distribution Networks,” vol. 25, no. 3, pp. 814–820, 2010.

[7] S. Ganguly, N. C. Sahoo, and D. Das, “Multi-objective particle swarm optimization based on fuzzy-Pareto-dominance for possibilistic planning of electrical distribution systems incorporating distributed generation,” *Elsevier Fuzzy Sets Syst.*, vol. 213, pp. 47–73, 2013.

[8] S. Ganguly and D. Samajpati, “Distributed Generation Allocation on Radial Distribution Networks Under Uncertainties of Load and Generation Using Genetic Algorithm,” *IEEE Trans. Sustain. Energy*, pp. 1–10, 2015.

[9] H. Musa, “A Review of Distributed Generation Resource Types and Their Mathematical Models for Power Flow Analysis,” *Int. J. Sci. Technol. Soc.*, vol. 3, no. 4, p. 204, 2015.

[10] D. K. Jagtap, K.M. ;Khatod, “Impact of different types of distributed generation on radial distribution network,” *Int. Conf. Reliab. Optim. Inf. Technol. (ICROIT), 2014*, pp. 473–476, 2014.

[11] P. Mehta, P. Bhatt, and V. Pandya, “Challenges and Solutions for Improvement in Radial Distribution Network : A Review,” *Int. Conf. “Women Sci. Technol. Creat. Sustain. Career” ICWSTCSC - 2016*, 2016.

[12] K. M. Jagtap and D. K. Khatod, “Allocation of distribution network losses with different types of distributed generation,” *12th IEEE Int. Conf. Electron. Energy, Environ. Commun. Comput. Control (E3-C3), INDICON 2015*, pp. 1–6, 2016.

[13] J. Teng, “Modelling distributed generations in three-phase distribution load flow,” *IET Gener. Transm. DIstrinbution*, vol. 2, no. April 2007, pp. 330–340, 2008.

[14] A. Hadian, S. Member, M. Haghifam, and S. Member, “Placement of DG with Stochastic Generation in t,” pp. 1–7, 2010.

[15] Y. M. Atwa, M. M. A. Salama, and R. Seethapathy, “Optimal Renewable Resources Mix for Distribution System Energy Loss Minimization,” vol. 25, no. 1, pp. 360–370, 2010.

[16] A. Ehsan and Q. Yang, “Optimal integration and planning of renewable distributed generation in the power distribution networks : A review of analytical techniques,” *Appl. Energy*, vol. 210, no. October 2017, pp. 44–59, 2020.

[17] X. Hu, Y. Gao, and Y. Zhao, “Multi-objective coordinated planning of distribution network frame incorporating multi-type distributed generation considering uncertainties,” *Int. Conf. Renew. Power Gener. (RPG 2015)*, pp. 1–6, 2015.

[18] Z. Liu, F. Wen, and G. Ledwich, “Optimal siting and sizing of distributed generators in distribution systems considering uncertainties,” *IEEE Trans. Power Deliv.*, vol. 26, no. 4, pp. 2541–2551, 2011.

[19] C. Wang and M. H. Nehrir, “Analytical Approaches for Optimal Placement of Distributed Generation Sources in Power Systems,” vol. 19, no. 4, pp. 2068–2076, 2004.

[20] D. Quoc, N. Mithulananthan, and K. Y. Lee, “Optimal placement of dispatchable and nondispatchable renewable DG units in distribution networks for minimizing energy loss,” *Int. J. Electr. POWER ENERGY Syst.*, vol. 55, pp. 179–186, 2014.

[21] K. Zou, “Distribution system planning with incorporation of distributed renewable energy resources,” University of Wollongong, 2011.

[22] Y. M. Atwa, S. Member, S. Member, M. M. A. Salama, and R. Seethapathy, “Optimal Renewable Resources Mix for Distribution

System Energy Loss Minimization," vol. 25, no. 1, pp. 360–370, 2010.

[23] H. Bahreyni, Seyed Amir Hosein; Shayanfar, "Loss Reduction in a Probablistic Approach for Optimal Planning of Renewable Resources," *Electr. Power Distrib. Conf.*, vol. 22, no. 18–19 April, pp. 18–19, 2017.

[24] I. . Kothari, D.P; Nagrath, *Modern Power System Analysis*, 3rd Editio. The McGraw-Hill Companies.

[25] T. Tayjasanant and V. Hengsritawat, "Comparative Evaluation ofDG and PV-DG Capacity Allocation in a Distribution System," pp. 293–298, 2012.

[26] Y. M. Atwa, S. Member, S. Member, R. Seethapathy, and M. A. Salama, "Effect of Wind-Based DG Seasonality and Uncertainty on Distribution System Losses," pp. 1–6, 2008.

[27] A. Hadian, S. Member, M. Haghifam, S. Member, J. Zohrevand, and S. Member, "Probabilistic Approach for Renewable DG Placement in Distribution Systems with Uncertain and Time Varying Loads," pp. 1–8, 2009.

[28] A. Hadian and M. R. Haghifam, "Placement of DG with stochastic generation," *2010 IEEE PES Transm. Distrib. Conf. Expo. Smart Solut. a Chang. World*, pp. 1–7, 2010.

[29] G. Carpinelli, G. Celli, S. Mocci, F. Pilo, and A. Russo, "Optimisation of embedded generation sizing and siting by using a double trade-off method," in *IEE Proceedings on Generation Transmission and DIstribution*, 2005, pp. 503–513.

[30] A. Sheela, M. Sowmya, and V. Gowri Shankar, "Optimal Placement and Sizing of Renewable Energy Generation Considering Uncertainties Using Intelligent Water Drops Algorithm," *Int. Conf. Innov. Information, Embed. Commun. Syst.*, no. Vci, pp. 12–15, 2017.

[31] J. K. L. Caasi, "Comparative Analysis of the Optimal Siting and Sizing on Different Solar Distributed Generation Models Through Stochastic Method," in *IEEE Innovative Smart Grid Technologies-Asia*, 2016, pp. 485–490.

[32] A. Carpinelli, G.; Celli, G.; Pilo, F.;Russo, "Distributed Generation Siting and Sizing under Uncertainty," in *IEEE Porto Power Tech Conference*, 2001.

[33] L. F. Ochoa, A. Padilha-feltrin, S. Member, and G. P. Harrison, "Time-Series-Based Maximization of Distributed Wind Power Generation Integration," *IEEE Trans. Energy Convers.*, vol. 23, no. 3, pp. 968–974, 2008.

[34] D. K. Khatod, V. Pant, and J. Sharma, "Evolutionary Programming Based Optimal Placement of Renewable Distributed Generators," *IEEE Trans. Power Syst.*, vol. 28, no. 2, pp. 683–695, 2013.

[35] K. Zou, A. P. Agalgaonkar, K. Muttaqi, and S. Perera, "Distribution System Planning With Incorporating DG Reactive Capability and System Uncertainties," *IEEE Trans. Sustain. Energy*, vol. 3, no. 1, pp. 112–123, 2012.